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(54) Title: AMINO ACIDS USEFUL AS INHIBITORS OF THE ADVANCED GLYCOSYLATION OF PROTEINS			
(57) Abstract			
The present invention relates to compositions and methods for inhibiting protein aging. Accordingly, a composition is disclosed which comprises an agent or compound capable of inhibiting the formation of advanced glycosylation end products of target proteins by reacting with the carbonyl moiety of the early glycosylation product of such target proteins formed by their initial glycosylation. Suitable agents are amino acids and their derivatives which contain an active nitrogen-containing group. Particular agents comprise lysine and mixtures thereof. The method comprises contacting the target protein with the composition. Both industrial and therapeutic applications for the invention are envisioned, as food spoilage and animal protein aging can be treated.			

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**AMINO ACIDS USEFUL AS INHIBITORS OF THE ADVANCED  
GLYCOSYLATION OF PROTEINS**

**RELATED PUBLICATIONS**

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The Applicants are co-authors of the following articles directed to the subject matter of the present invention: "COVALENT ATTACHMENT OF SOLUBLE PROTEINS BY NONENZYMATIALLY GLYCOSYLATED COLLAGEN; ROLE IN THE IN SITU FORMATION OF IMMUNE COMPLEXES, Brownlee, M., Pongor, S., Cerami, A., J. Exp. Med., 158, pp. 1739-1744 (1983); "AGING OF PROTEINS: ISOLATION AND IDENTIFICATION OF A FLUORESCENT CHROMOPHORE FROM THE REACTION OF POLYPEPTIDES WITH GLUCOSE", Pongor, S., Ulrich, P., Bencsath, A. A., and Cerami, A., Proc. Natl. Acad. Sci. USA, 81, pp. 2682-2688 (1984); and "ADVANCED GLYCOSYLATION END PRODUCTS IN TISSUE AND THE BIOCHEMICAL BASIS OF DIABETIC COMPLICATIONS", Brownlee, M., Cerami, A., and Vlassara, H., The New England Journal of Medicine, 318, pp. 1315-1321 (1988). All of the above publications are incorporated herein by reference.

**BACKGROUND OF THE INVENTION**

25 The present invention relates generally to the aging of proteins resulting from reaction of glucose, and particularly to the nonenzymatic glycosylation of proteins and subsequent reactions leading to advanced glycosylation end products, and to methods and agents for 30 their inhibition.

The reaction between glucose and proteins has been known for some time. Its earliest manifestation was in the appearance of brown pigments during the cooking of food, 35 which was identified by Maillard in 1912, who observed that glucose or other reducing sugars react with amino acids to form adducts that undergo a series of dehydrations and rearrangements to form stable brown

pigments, Maillard, L.D. C.R. Acad. Sci., 154, pp. 66-68 (1912).

In the years that followed the initial discovery by  
5 Maillard, food chemists studied the hypothesized reaction  
in detail and determined that stored and heat treated  
foods undergo nonenzymatic browning as a result of the  
reaction between glucose and the polypeptide chain, and  
that the proteins are resultingly crosslinked and  
10 correspondingly exhibit decreased bioavailability. At  
this point, it was determined that the pigments  
responsible for the development of the brown color that  
develops as a result of protein glycosylation possessed  
characteristic spectra and fluorescent properties;  
15 however, the chemical structure of the pigments had not  
been specifically elucidated.

The reaction between reducing sugars and food proteins  
discussed above was found in recent years to have its  
20 parallel in vivo. Thus, the nonenzymatic reaction  
between glucose and the free amino groups on proteins to  
form a stable amino, 1-deoxy ketosyl adduct, known as the  
Amadori product, has been shown to occur with hemoglobin,  
wherein a rearrangement of the amino terminal of the  $\beta$ -  
25 chain of hemoglobin by reaction with glucose, forms the  
adduct known as hemoglobin A<sub>1c</sub>. The reaction has also  
been found to occur with a variety of other body  
proteins, such as lens crystallins, collagen and nerve  
proteins. See Bunn, H.F., Haney, D.N., Gabbay, K.H. and  
30 Gallop, P.H., Biochem. Biophys. Res. Comm., 67, pp. 103-  
109 (1975); Koenig, R.J., Blobstein, S.H. and Cerami, A.,  
J. Biol. Chem., 252, pp. 2992-2997 (1975); Monnier, V.M.  
and Cerami, A. in Maillard Reaction in Food and  
Nutrition, ed. Waller, G.A., American Chemical Society,  
35 215, pp. 431-448 (1983); and Monnier, V.M. and Cerami,  
A., Clinics in Endocrinology and Metabolism, 11, pp. 431-  
452 (1982).

Moreover, brown pigments with spectral and fluorescent properties similar to those of late-stage Maillard products have also been observed in vivo in association with several long-lived proteins, such as lens proteins and collagen from aged individuals. An age-related linear increase in pigment was observed in human dura collagen between the ages of 20 to 90 years. See Monnier, V.M. and Cerami, A., Science, 211, pp. 491-493 (1981); Monnier, V.M. and Cerami, A., Biochem. Biophys. Acta, 760, pp. 97-103 (1983); and Monnier, V.M., Kohn, R.R. and Cerami, A., "Accelerated Age-Related Browning of Human Collagen in Diabetes Mellitus", Proc. Natl. Acad. Sci., 81, pp. 583-587 (1984). Interestingly, the aging of collagen can be mimicked in vitro by the crosslinking induced by glucose; and the capture of other proteins and the formation of adducts by collagen, also noted, is theorized to occur by a crosslinking reaction, and is believed to account for the observed accumulation of albumin and antibodies in kidney basement membrane. See Brownlee, M., Pongor, S. and Cerami, A., J. Exp. Med., 158, pp. 1739-1744 (1983); and Kohn, R. R., Cerami, A. and Monnier, V.M., Diabetes, 33(1), pp. 57-59 (1984).

Recently, the role of other naturally-occurring reducing sugars, including fructose, in nonenzymatic cross-linking has been discussed. Specifically, Suarez et al. "Administration of an Aldose Reductase Inhibitor Induces a Decrease of Collagen Fluorescence in Diabetic Rats", J. Clin. Invest., 82, pp. 624-627 (1988) have shown that fructose levels are elevated in diabetes as a result of the elevated glucose being channeled through the polyol pathway, first to sorbitol then to fructose. These investigators also showed that the ability of fructose to cause nonenzymatic crosslinking as measured by collagen fluorescence, is 10 times greater than that of glucose. Because the methods and agents of the present invention block nonenzymatic crosslinking mediated by any of the

reactive sugars, they are expected to prevent fructose-mediated crosslinking as well. Cross-linking caused by other reactive sugars present in vivo or in foodstuffs, including ribose and galactose, would also be prevented 5 by the methods and compositions of the present invention.

In parent Application Serial No. 590,820 (now U.S. Patent No. 4,665,192) and in Pongor, S.M., et al., supra, both incorporated herein by reference, a fluorescent 10 chromophore was isolated and identified which was found to be present in certain browned polypeptides such as bovine serum albumin and poly-L-lysine, and was assigned the structure 2-(2-furoyl)-4(5)-2(furanyl)-1H-imidazole. The compound was found to exist in a tautomeric state and 15 has incorporated in its structure two peptide-derived amine nitrogens. The incorporation of these amine nitrogens and two glucose residues in the compound suggested that its peptide-bound precursor may be implicated in the in vivo crosslinking of proteins by 20 glucose, which is observed in the late stage of the Maillard process. [See Chang, J.C.F., Ulrich, P.C., Bucala, R. and Cerami, A., J. Biol. Chem., 260, pp. 7970-7974 (1985)]. This chromophore made possible the identification of the advanced glycosylation end products 25 and assisted additional investigations seeking to clarify the protein aging process and to identify the specific chemistry involved in order to develop methods and agents for its inhibition. It is to this purpose that the present Application is directed.

30 More recently, other advanced glycosylation products have been identified, such as Farmar et al., U.S. Serial Number 097,856, filed September 17, 1987; pyrraline (Hayase et al., "Aging of Proteins: Immunological 35 Detection of a Glucose-derived Pyrrole Formed during Maillard Reaction in Vivo", J. Biol. Chem., 263, pp. 3758-3764 (1989)), pentosidine (Sell, D. and Monnier V.

"Structure Elucidation of a Senescence Cross-link from Human Extracellular Matrix" J. Biol. Chem., 264, pp. 21597-21602 (1989)). Formation of these advanced glycosylation products would be inhibited by the methods 5 and agents of the present invention. The present invention is not restricted to any of these advanced glycosylation endproducts specifically, but to the general process of their formation as a result of the reaction of proteins with sugars.

10

SUMMARY OF THE INVENTION

In accordance with the present invention, a method and associated agents are disclosed for the inhibition of 15 protein aging. In particular, agents for inhibiting protein aging due to the formation of advanced glycosylation end products may be selected from those materials capable of reacting with the early glycosylation product from the reaction of glucose with 20 proteins and preventing further reactions. Thus, for example, compounds or compositions having active nitrogen-containing substituents such as hydrazine groups, have been theorized to be suitable, and compounds such as aminoguanidine,  $\alpha$ -hydrazinohistidine and lysine 25 have been found to be suitable. These agents appear to react with the early glycosylation product at its reactive carbonyl and thereby prevent the same from later forming the advanced glycosylation end products which lead to protein crosslinks.

30

Particularly suitable agents for use in the present invention are amino acids and their derivatives of the formula

35



wherein R is selected from the group consisting of hydrogen; lower alkyl, optionally substituted by one or two hydroxyl, thiol, phenyl, hydroxyphenyl, lower alkylthiol, carboxy, aminocarboxy or amino groups; and 5 their biocompatible and pharmaceutically acceptable acid addition salts.

The lower alkyl groups referred to herein contain 1-6 carbon atoms and include methyl, ethyl, propyl, butyl, 10 pentyl, hexyl and the corresponding branched chain isomers thereof.

The amino acids utilized herein can possess either the L&D stereochemical configuration or be utilized as 15 mixtures thereof. However, the L-configuration is preferred.

Equivalent to the compounds of Formula I for the purposes of this invention are the biocompatible and 20 pharmaceutically acceptable salts thereof. Such salts can be derived from a variety of inorganic and organic acids such as methanesulfonic, hydrochloric, toluenesulfonic, sulfuric, maleic, acetic, phosphoric and related acids.

25 Of the compounds encompassed by Formula I, certain substituents are preferred.

Representative compounds of the present invention are: 30 lysine; 2,3-diaminosuccinic acid; cysteine and the biocompatible and pharmaceutically acceptable salts thereof.

The present invention also relates to a method for 35 inhibiting protein aging by contacting the initially glycosylated protein at the stage of the early glycosylation product with a quantity of one or more of

the agents of the present invention. In the instance where the present method has industrial application, one or more of the agents may be applied to the proteins in question, either by introduction into a mixture of the

- 5 same in the instance of a protein extract, or by application or introduction into foodstuffs containing the protein or proteins, all to prevent premature aging and spoilage of the particular foodstuffs.

- 10 In the instance where the present method has therapeutic application, the animal host intended for treatment may have administered to it a quantity of one or more of the agents, in a suitable pharmaceutical form. Administration may be accomplished by known techniques,  
15 such as oral, topical and parenteral techniques such as intradermal, subcutaneous, intravenous or intraperitoneal injection, as well as by other conventional means. Administration of the agents may take place over an extended period of time at a dosage level of, for  
20 example, up to about 25 mg/kg.

The ability to inhibit the formation of advanced glycosylation end products carries with it significant implications in all applications where protein aging is a  
25 serious detriment. Thus, in the area of food technology, the retardation of food spoilage would confer an obvious economic and social benefit by making certain foods or marginal stability less perishable and therefore more available for consumers. Spoilage would be reduced as  
30 would the expense of inspection, removal and replacement, and the extended availability of the foods could aid in stabilizing their price in the marketplace. Similarly, in other industrial applications where the perishability of proteins is a problem, the admixture of the agents of  
35 the present invention in compositions containing such proteins would facilitate the extended useful life of the same. Presently used food preservatives and

discoloration preventatives such as sulfur dioxide, known to cause toxicity including allergy and asthma in animals, might be replaced with compounds such as those described herein.

5

The present method has particular therapeutic application as the Maillard process acutely affects several of the significant protein masses in the body, among them collagen, elastin, lens proteins, and the kidney

10 glomerular basement membranes. These proteins deteriorate both with age (hence the application of the term "protein aging") and as one of the sequelae of diabetes. Consequently, the ability to either retard or substantially inhibit the formation of advanced  
15 glycosylation end products carries the promise of favorably treating a significant adverse effect of diabetes and, of course, improving the quality and perhaps duration of animal life.

20 Accordingly, it is a principal object of the present invention to provide a method for inhibiting the extensive cross-linking of proteins that occurs as an ultimate consequence of the reaction of the proteins with glucose or other reducing sugars, by correspondingly  
25 inhibiting the formation of advanced glycosylation end products.

It is a further object of the present invention to provide a method as aforesaid which is characterized by a  
30 reaction with early glycosylation products.

It is a further object of the present invention to provide a method as aforesaid which prevents the rearrangement and cross-linking of the said early  
35 glycosylation products to form the said advanced glycosylation end products.

It is a yet further object of the present invention to provide agents capable of participating in the reaction with the said early glycosylation products in the method as aforesaid.

It is a still further object of the present invention to provide therapeutic methods of treating the adverse consequences of protein aging, manifest in the embrittlement of animal protein and the browning and 10 spoilage of foodstuffs.

Other objects and advantages will become apparent to those skilled in the art from a consideration of the ensuing description which proceeds with reference to the 15 following illustrative drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a graph showing the results of studies aimed 20 at inhibiting the formation of advanced glycosylation end products in albumin which had been reacted with a quantity of glucose, on an in vitro basis.

FIGURE 2 is a graph showing the results of studies aimed 25 at inhibiting protein entrapment and accumulation by glycosylated structural proteins such as collagen.

FIGURE 3A is a graph of the degree of solubilization of collagen incubated with glucose, with and without 30 treatment with an agent of the present invention.

FIGURE 3B is a photograph of a polyacrylamide gel showing separation of protein fragments after cyanogen bromide digestion of collagen incubated with glucose with and 35 without an agent of the present invention.

FIGURE 4 is a graph of the results of an in vivo study examining the extent of protein bound to the glomerular basement membrane of diabetic rats to certain of which an agent of the present invention had been administered.

5

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

- In accordance with the present invention, compositions and associated methods have been developed which inhibit 10 the formation of advanced glycosylation end products in a number of target proteins existing in both animals and plant material. In particular, the invention relates to compositions which may contain one or more agents that are capable of inhibiting the formation of advanced 15 glycosylation end products on such target proteins, by reacting with the carbonyl moiety of the early glycosylation product that is formed by the initial glycosylation of the protein.
- 20 It is the carbonyl group located near the junction between sugar and protein segments of the early glycosylation product that is theorized to comprise an active site that causes the further cross-linking of the protein to form the advanced glycosylation end product, 25 and likewise contributes to the entrapment of other proteins that is evident in the development in vivo of conditions such as skin wrinkling, certain kidney diseases, atherosclerosis, osteoarthritis and the like. Similarly, plant and animal material that undergoes 30 nonenzymatic browning deteriorates and, in the case of foodstuffs, become spoiled or toughened and consequently, inedible. Thus, the reaction of the compounds of this invention with this carbonyl moiety is believed to inhibit the late stage Maillard effect and intervene in 35 the deleterious changes described above.

The rationale of the invention is to use agents which block the post-glycosylation step, i.e., the formation of fluorescent chromophores such as that identified in Pongor, et al., supra and Farmar et al., supra, among 5 others, whose presence is associated with, and leads to, the adverse sequelae of diabetes and aging. An ideal agent would prevent the formation of a chromophore and its associate cross-links of proteins to proteins and trapping of proteins on the other proteins, such as that 10 which occurs in arteries and in the kidney.

The present invention does not attempt to prevent initial protein glycosylation, as it would be nearly impossible to use agents which prevent the reaction of glucose with 15 protein amino groups. The agents that are capable of preventing initial glycosylation are likely to be highly toxic, and since the initial glycosylation comes to equilibrium in about three weeks, there is inadequate time available to achieve this objective. Instead, the 20 ideal agent would prevent or inhibit the long-term, post-glycosylation steps that lead to the formation of the ultimate advanced glycosylation end products that are a direct cause of the pathology associated with aging and diabetes.

25 The chemical nature of the early glycosylation products with which the compounds of the present invention is believed to react are speculative. Early glycosylation products with carbonyl moieties which are involved in the 30 formation of advanced glycosylation products, and which may be blocked by reaction with the compounds of the present invention, have been postulated. In one case, the reactive carbonyl moieties of Amadori products or their further dehydration and/or rearrangement products, 35 may condense to form advanced glycosylation endproducts. Another proposed mechanism is the formation of reactive carbonyl compounds, containing one or more carbonyl

moieties (such as glycoaldehyde or 3-deoxyglucosone) from the cleavage of Amadori or other early glycosylation products (see, for example, Gottschalk, A. (1972) in *The Glycoproteins* (Gottschalk, A., ed) Part A, pp. 141-157, Elsevier Publishing Co., New York; Reynolds, T.M. (1965) *Adv. Food Res.*, 14, pp. 167-283), and by subsequent reactions with an amine or Amadori product to form carbonyl containing advanced glycosylation products such as the alkylformylglycosylpyrroles described by Farmar et al, supra.

Several investigators have studied the mechanism of advanced glycosylation product formation. In vitro studies by Eble et al., (1983), "Nonenzymatic 15 Glucosylation and Glucose-dependent Cross-linking of Protein", *J. BIOL. CHEM.*, 258:9406-9412, concerned the crosslinking of glycosylated protein with nonglycosylated protein in the absence of glucose. Eble et al. sought to elucidate the mechanism of the Maillard reaction and 20 accordingly conducted controlled initial glycosylation of RNAase as a model system, which was then examined under varying conditions.

In one aspect, the glycosylated protein material was 25 isolated and placed in a glucose-free environment and thereby observed to determine the extent of cross-linking. Eble et al. thereby observed that cross-linking continued to occur not only with the glycosylated protein but with non-glycosylated proteins as well. One of the 30 observations noted by Eble et al. was that the reaction between glucose and the protein material appeared to occur at the location on the protein chain of the amino acid lysine. Confirmatory experimentation conducted by Eble et al. in this connection demonstrated that free 35 lysine would compete with the lysine on RNAase for the binding of glucose. Thus, it might be inferred from these data that lysine may serve as an inhibitor of

- advanced glycosylation; however, this conclusion and the underlying observations leading to it should be taken in the relatively limited context of the model system prepared and examined by Eble et al. Clearly, Eble et al. does not appreciate, nor is there a suggestion therein, of the discoveries that underlie the present invention, with respect to the inhibition of advanced glycosylation of proteins both in vitro and in vivo.
- 10 The experiments of Eble et al. do not suggest the reactive cleavage product mechanism or any other mechanism in the in vivo formation of advanced glycosylation endproducts in which glucose is always present. In fact, other investigators support this
- 15 mechanism to explain the formation of advanced glycosylated endproducts in vivo (see for example Hayase et al, 1989, supra; Sell and Monnier, 1989, supra; Oimomi et al., AGRIC. BIOL. CHEM., 53(6):1727-1728 (1989); and Diabetes Research and Clinical Practice, 6:311-313
- 20 (1989). The use of lysine as an inhibitor in the Eble et al. model system has no bearing upon the utility of the compounds of the present invention in the inhibition of advanced glycosylated endproducts formation in the presence of glucose in vivo and the amelioration of
- 25 complications of diabetes and aging.

Accordingly, the compositions useful in the present invention comprise or contain agents capable of reacting with the active carbonyl intermediate of the early

30 glycosylation product. Suitable agents include compounds having an active nitrogen-containing group or substituent such as a hydrazine group. Also, the agent of compound may be at least partially derived from an amino acid, including the esters and amides thereof, as compounds

35 having this derivation are generally biocompatible with the target proteins to be contacted. For example, the agent may comprise a compound such as aminoguanidine,  $\alpha$ -

- hydrazinohistidine and lysine, or mixtures of these agents or compounds. Each of these agents or compounds possesses an active nitrogen-containing substituent that is believed to react with the carbonyl of the early 5 glycosylation product. Consequently, reaction of the agents with the glycosyl-lysine moiety of a protein would prevent this moiety from forming crosslinks with other groups.
- 10 Hollis and Strickberger (Diabetologia 28:282-5 [1985]) found that in vivo administration of the compound  $\alpha$ -hydrazinohistidine, a known inhibitor of the enzyme histidine decarboxylase, reduces the accumulation of albumin in the aortas of rats. The authors proposed that 15 the drug acted to reduce production of histamine in this tissue, and that histamine is therefore the mediator of low density lipoprotein accumulation which is implicated in atherosclerotic disease. In contrast, aminoguanidine is known to increase levels of histamine (See Lindberg et 20 al., Acta Obst. Gynecol. Scandinav., 45: 131-139, (1966)) and  $\alpha$ -hydrazinohistidine and aminoguanidine therefore have opposing effects on histamine levels. It can therefore be seen that the present findings that both 25  $\alpha$ -hydrazinohistidine and aminoguanidine have efficacy in vivo and in vitro to reduce protein crosslinking rules out from consideration and consequently distinguishes the mechanism proposed by Hollis and Strickberger as the explanation of the manner in which the compounds of the present invention might work to reduce advanced glycosylation end product formation. Moreover, the 30 findings of Hollis and Strickberger are distinguishable from the concept and application of the present invention because the mechanism of histamine synthesis suppression by  $\alpha$ -hydrazinohistidine suggested by the authors is 35 functionally distinct from the underlying concept of the present invention, and it is believed, may even be placed in question by the latter.

Thus, the agents of the present invention have been identified and tested on the basis of their ability to react with the carbonyl moiety of the early glycosylation product to form a highly stable adduct, and would not 5 have been suggested from the work of Hollis and Strickberger.

The compound aminoguanidine is known to have low toxicity in animals. According to the 1978 Registry of Toxic 10 Effects of Chemical Substances, aminoguanidine base has a LD<sub>50</sub> when administered subcutaneously of 1258 mg/kg in rats and 963 mg/kg in mice. The hydrochloride derivative had a LD<sub>50</sub> in rats of 2984 mg/kg when given subcutaneously. The latter compound exhibits very low 15 toxicity.

In the instance where the composition of the present invention is utilized for in vivo or therapeutic purposes, it may be noted that the compounds or agents 20 used therein are biocompatible. Pharmaceutical compositions may be prepared with a pharmaceutically effective quantity of the agents or compounds of the present invention and may include a pharmaceutically acceptable carrier, selected from known materials 25 utilized for this purpose. Such compositions may be prepared in a variety of forms, depending on the method of administration. For example, aminoguanidine may be derivatized to the hydrochloride salt from the commercially available bicarbonate salt to improve its 30 solubility and to make it less irritating for intraperitoneal injection. Also, a liquid form would be utilized in the instance where administration is by intravenous or intraperitoneal injection, while, if appropriate, tablets, capsules, etc., may be prepared for 35 oral administration. For application to the skin, a lotion or ointment may be formulated with the agent in a suitable vehicle, perhaps including a carrier to aid in

penetration into the skin. Other suitable forms for administration to other body tissues are also contemplated.

- 5 The present invention likewise relates to methods for inhibiting the formation of advanced glycosylation end products, which comprise contacting the target proteins with the composition of the present invention. In the instance where the target proteins are contained in  
10 foodstuffs, whether plant or animal origin, these foodstuffs could have applied to them by various conventional means a composition containing the present agents. Likewise, in the instance where therapeutic applications are intended, the animals to be treated  
15 would have administered to them a regular quantity of the pharmaceutical composition of the present invention. Administration could take place, for example, daily, and an effective quantity of the agent or compound of the present invention could range up to 25 mg/kg of body  
20 weight of the animal. A topical preparation may, for example, include up to 10% of the agent or composition in an ointment or lotion for application to the skin. Naturally, some variation in these amounts is possible, and the suggested amounts are provided in fulfillment of  
25 applicants' duty to disclose the best mode for the practice of the present invention.

As is apparent from a discussion of the environment of the present invention, the present methods and  
30 compositions hold the promise for arresting the aging of key proteins both in animals and plants, and concomitantly, conferring both economic and medical benefits as a result thereof. In the instance of foodstuffs, the administration of the present composition  
35 holds the promise for retarding food spoilage thereby making foodstuffs of increased shelf life and greater availability to consumers. Replacement of currently-used

preservatives, such as sulfur dioxide known to cause allergies and asthma in humans, with non-toxic, biocompatible compounds is a further advantage of the present invention.

5

The therapeutic implications of the present invention relate to the arrest of the aging process which has, as indicated earlier, been identified in the aging of key proteins by advanced glycosylation and crosslinking.

- 10 Thus, body proteins, and particularly structural body proteins such as collagen, elastin, lens proteins, nerve proteins and kidney glomerular basement membranes would all benefit in their longevity and operation from the practice of the present invention. The present invention  
15 thus reduces the incidence of pathologies involving the entrapment of proteins by crosslinked target proteins, such as retinopathy, cataracts, diabetic kidney disease, glomerulosclerosis, peripheral vascular disease, arteriosclerosis obliterans, peripheral neuropathy,  
20 stroke, hypertension, atherosclerosis, osteoarthritis, periarthritis rigidity, loss of elasticity and wrinkling of skin, stiffening of joints, glomerulonephritis, etc. Likewise, all of these conditions are in evidence in patients afflicted with diabetes mellitus. Thus, the  
25 present therapeutic method is relevant to treatment of the noted conditions in patients either of advanced age or those suffering from one of the mentioned pathologies.

- 30 Protein crosslinking through advanced glycosylation product formation can decrease solubility of structural proteins such as collagen in vessel walls (see Brownlee et al., Science, 232, pp. 1629-1632, (1986)), and as well as trap serum proteins, such as lipoproteins to the collagen. Also, this may result in covalent trapping of  
35 extravasated plasma proteins in subendothelial matrix, and reduction in susceptibility of both plasma and matrix proteins to physiologic degradation by enzymes. (See

Brownlee et al., Diabetes, 35, Suppl. 1, p. 42A (1986).) For these reasons, the progressive occlusion of diabetic vessels induced by chronic hyperglycemia has been hypothesized to result from excessive formation of 5 glucose-derived crosslinks. Such diabetic macrovascular changes and microvascular occlusion can be effectively prevented by chemical inhibition of advanced glycosylation product formation utilizing a composition and the methods of the present invention.

10

Other studies indicate that the development of chronic diabetic damage in target organs is primarily linked to hyperglycemia so that tight metabolic control would delay or even prevent end-organ damage. See Nicholls et al., 15 Lab. Invest., 60(4), p. 486 (1989), which discusses the effects of islet isografting and aminoguanidine in murine diabetic nephropathy. These studies further evidence that aminoguanidine, an agent of the present invention, diminishes kidney glomerular basement membrane protein 20 crosslinking in diabetic rats and extends the earlier studies of Brownlee et al., Science, 232, pp. 1629-1632 (1986) to this additional target organ of complication of diabetes. An additional study showed the reduction of immunoglobulin trapping in the kidney by aminoguanidine 25 (Brownlee et al., Diabetes, 35, Suppl. 1, p. 42A (1986)).

Further evidence in the streptozotocin-diabetic rat model that aminoguanidine administration intervenes in the development of diabetic nephropathy was presented by 30 Brownlee et al., 1988, supra, with regard to morphologic changes in the kidney which are hallmarks of diabetic renal disease. These investigators reported that the increased glomerular basement membrane thickness, a major structural abnormality characteristic of end-stage 35 diabetic renal disease, was prevented with aminoguanidine.

Taken together, these data strongly suggest that inhibition of the formation of advanced glycosylation endproducts (AGE's), by the teaching of the present invention, may prevent late as well as early structural 5 lesions due to diabetes, as well as changes during aging caused by the formation of AGE's.

Diabetes-induced changes in the deformability of red blood cells, leading to more rigid cell membranes, is 10 another manifestation of cross-linking and aminoguanidine has been shown to prevent it in vivo.

Increased cross-linking of collagen in diabetic rats has shown to be prevented by aminoguanidine. Oxlund and 15 Andreassen, "The increase in biochemical and biomechanical stability of collagen in diabetic rats is prevented by aminoguanidine treatment", European Association for the Study of Diabetes, Twenty-fifth Annual Meeting, p. 525A, Abstract No. 371, 1989 showed 20 the effect when thermal stability of tendon fibers was assessed by breaking time in a urea bath, as well as mechanical strength. Soulis et al., "Aminoguanidine reduces tissue fluorescence but not albuminuria in diabetic rats". NIH Conference on the Maillard Reaction 25 in Aging, Diabetes, and Nutrition, Bethesda, Maryland, September 22-23, 1988, page 30) showed the same effect on collagen in the aorta, measured by fluorescence and solubility.

30 Giambione and Brownlee, "Aminoguanidine Treatment Normalizes Increased Steady-state Levels of Laminin B1 mRNA in Kidneys of Long-term Streptozotocin-diabetic Rats" Diabetes 38, Supplement 2:83A Forty-ninth Annual Meeting, American Diabetes Association (1989) showed that 35 aminoguanidine treatment to diabetic rats prevents the diabetes-induced increase in laminin mRNA in the kidney. This indicates that aminoguanidine may prevent

20

overproduction of matrix, which leads to basement membrane thickening and morphologic and functional deterioration of vasculature in kidneys and other organs.

5 A further consequence of diabetes is the effect of hyperglycemia on bone matrix differentiation resulting in decreased bone formation usually associated with chronic diabetes. In animal models, diabetes reduces matrix-induced bone differentiation by 70% and in vitro models  
10 mimic this effect. Aminoguanidine prevents the decreased bone formation in this model.

The present invention will be better understood from a consideration of the following illustrative examples,  
15 reviewing the selection and testing of certain of the agents of the present invention on both an in vitro and in vivo basis.

#### EXAMPLE I

20 To measure the ability of certain of the agents of the present invention to inhibit the production of advanced glycosylated end products in vitro, albumin and glucose were incubated together for two weeks in the presence of  
25 several test agents. Samples were taken at regular intervals for analysis. Advanced glycosylation end products were measured as appearance of fluorescent compounds, and early glycosylation products were measured by incorporation of radiolabeled glucose into albumin.  
30 Reaction conditions were as follows. Each mixture contained 6 mg/mL bovine serum albumin, 200 mM glucose, 200 mM test agent (either aminoguanidine hydrochloride,  $\alpha$ -hydrazinohistidine, or lysine), and approximately  $9.5 \times 10^6$  counts per minute of  $^{14}\text{C}$ -glucose in 0.5M phosphate  
35 buffer, pH 7.6. The radiolabeled glucose was prepurified before use to eliminate breakdown products which might react with the albumin and lead to an erroneous

indication of the degree of early glycosylation product formation. Reaction mixtures were incubated at 37°C, and samples were taken after 0.5, 1.0, 1.5, and 2 weeks. Control mixtures lacked glucose or agent.

5

After the incubation periods, samples were treated as follows. After dialysis to remove all unbound glucose, the amount of protein present was measured with a standard dye-binding assay. The amount of glucose which 10 became bound to the albumin, a measure of early glycosylation products, was determined by precipitating albumin with trichloroacetic acid and measuring the radioactivity of the bound glucose using scintillation counting. Advanced glycosylation end products were 15 quantitated by determining the fluorescence of the albumins described in parent Application Serial No. 590,820, and as described by Pongor et al., *supra*. Spectral measurements on excitation and emission maxima were made on all samples to ensure that these values had 20 not been shifted as a result of adduct formation with inhibitors.

The results of this experiment are expressed graphically 25 in Figure 1. For each sample, incorporation of radiolabeled glucose is indicated by the solid portion of the bar, and fluorescence is indicated in the open portion of the bar. All values are expressed as per milligram of albumin. In all further discussions, aminoguanidine refers to the hydrochloride derivative.

30

The results show that the glucose and albumin react to form a large amount of fluorescent advanced glycosylation end products after 0.5, 1, 1.5 and 2 weeks of incubation ("GLUCOSE + BSA"). Inclusion of 200 mM aminoguanidine 35 dramatically reduced by as much as eightfold with formation of fluorescent compounds, by comparison with the control samples after a two-week incubation ("BSA +

GLUCOSE + I#2). Inclusion of 200 mM  $\alpha$ -hydrazinohistidine also reduced formation of advanced glycosylation end products as measured by fluorescence ("BSA + GLUCOSE + I#1). Lysine appeared to cause an increase in 5 fluorescent compound formation ("BSA + GLUCOSE + LYS"), but as will be seen in the next experiment, it had the ability to reduce protein crosslinking. The amount of early glycosylation end products, as measured by glucose incorporation, was nearly unchanged in all reactions.

10 The control incubation without glucose showed little development of fluorescent products (A).

These results show that aminoguanidine, and to a lesser extent,  $\alpha$ -hydrazinohistidine, reduce the formation of 15 fluorescent compounds when glucose and albumin react over time, and indicate that these two agents reduce the amount of advanced glycosylation end products which form. The agents do not alter the formation of early glycosylation products.

20

#### EXAMPLE II

To more precisely measure the effect of the agents on the inhibition of protein crosslinking, an assay system was 25 devised to measure the extent of in vitro binding of a soluble protein to an insoluble protein. This assay system mimics the events which occur in tissues in which serum proteins become bound to proteins in extravascular matrix and which lead to accumulation of protein and 30 narrowing of vessel lumina in several other tissues. These events in vivo give rise to kidney disease and atherosclerotic disease, and lead to the pathologies associated with diabetes and aging.

35 To measure protein trapping (i.e., binding or accumulation), gelatin (collagen) was coupled to activated agarose beads (Affigel 10, Bio-Red

Laboratories) by routine methods. After coupling, all remaining active sites on the beads were quenched by reaction with glycine ethyl ester.

- 5 The beads were incubated for two weeks with bovine serum albumin and 400 mN glucose-6-phosphate, a more reactive form of glucose which forms early glycosylation products with proteins more rapidly than does glucose. Also included in some experiments were the test agents,
- 10 aminoguanidine,  $\alpha$ -hydrazinohistidine, or lysine, at a concentration of 200 mN. The bovine serum albumin was radioiodinated so that the amount which became bound to the beads could be measured. The amount of radiolabel that became bound to the beads is a direct measure of
- 15 protein trapping.

After a two-week incubation of the reaction mixtures at 37°C, the beads were washed extensively with chaotropic agents and the covalently bound radioactivity was determined. The results are set forth in Figure 2.

The left bar shows the control level of radiolabel incorporated into the beads in the absence of glucose-6-phosphate and in the absence of any test agents ("CONTROL COLLAGEN"). The second bar shows the high amount of incorporation in the presence of glucose-6-phosphate ("NEG. COLLAGEN"). This is likened to the presence of high concentrations of glucose in the blood of uncontrolled patients with diabetes and the pathological sequelae which result.

Figure 2 shows that the amount of protein trapping in the presence of either aminoguanidine ("NEG. COLLAGEN + 1#2") or  $\alpha$ -hydrazinohistidine ("NEG. COLLAGEN + I#") is greatly reduced. Lysine also reduced the amount of protein trapping to an extent similar to that of aminoguanidine (not shown). The results show the potential value of

these compounds *in vivo* for reducing the trapping or soluble protein on to membranes and other tissues, and further evidence that these agents may be of value in reducing the pathogenesis of diabetes and aging.

5

### EXAMPLE III

As a further evaluation of the compound aminoguanidine as a model for the prevention of protein trapping, 10 crosslinking and formation of advanced glycosylation end products, the following experiment using calf skin collagen was performed. Collagen is a protein in the skin responsible for the suppleness of skin, and crosslinking leads to wrinkling, decreased elasticity, 15 reduced susceptibility to proteolytic degradation, and other changes.

Collagen from samples of calf skin were extracted into acetic acid and then precipitated with 0.6 M sodium 20 chloride. These procedures removed from the solution skin collagen that was already permanently crosslinked or denatured. Native collagen fibrils were reformed by dialysis against 0.02M phosphate buffer, and these were incubated for 3 weeks at 35° C in the presence of 140 mM 25 glucose and with or without 200 mM aminoguanidine. After incubation, the samples were dialyzed and the degree of crosslinking was determined by two methods. First, the amount of reacted collagen which could be solubilized by treatment in 2% sodium dodecyl sulfate at 100° C was 30 measured.

As shown in Figure 3A, collagen incubated with glucose and aminoguanidine was as soluble as collagen incubated in buffer alone. In contrast, collagen incubated in 35 glucose without aminoguanidine was only 50% as soluble. This is further evidence that aminoguanidine has utility.

in the prevention of age-related changes in skin and other tissues.

The reacted collagen was further examined by cleaving it  
5 into fragments using cyanogen bromide treatment in formic acid. the resulting protein fragments were separated by size by sodium dodecyl sulfate - polyacrylamide gel electrophoresis. After electrophoresis, the protein fragments were identified in the gel using silver  
10 staining. The gel is shown in Figure 3B.

Referring to Figure 3B, Lane C contains collagen that was incubated with glucose alone. It is noted that a large amount of high molecular weight fragments form a  
15 continuous band at the top of the gel, indicating a large range of high molecular weight fragments. Some of this material could not enter the gel and is present in the 30% stacking gel above the gradient gel. Lane B contains the collagen incubated with glucose and aminoguanidine,  
20 and it is noted that there is no large amount of high molecular weight material at the top of the lane, as all of the protein fragments separate well in the lower part of the gel. Lanes A and D show collagen incubated in PBS alone or held frozen during the incubation of the other  
25 samples, respectively. The far left lane is a series of molecular weight markers. Identical results were observed with and without the presence of disulfide bond reducing agents in the electrophoresis buffer.

30 The above data indicate that aminoguanidine reduces the amount of crosslinking which occurs when collagen is incubated with glucose, and suggest the utility of this agent for topical application to skin to prevent age-related changes, including loss of elasticity and  
35 wrinkling.

The above in vitro experiments all point to the value of aminoguanidine as an agent to inhibit the formation of advanced glycosylation end products which form in vitro from proteins incubated in the presence of glucose or 5 other reducing sugars. As glucose is present in the body and is elevated in amount in diabetes, and as proteins in the body are known to undergo crosslinking and form fluorescent compounds all indicative of advanced glycosylation end products, use of this agent in vivo 10 would be useful in the prevention of the pathology associated with diabetes and changes that occur during aging.

Accordingly, the following experiment was performed to 15 test the hypothesis of the present invention in an in vivo experiment.

#### EXAMPLE IV

20 To measure the level of advanced glycosylation end products in vivo, the kidneys of rats were examined for serum proteins which had become attached to glomerular basement membranes. This was determined to be a good model in which to study this process as it is known that 25 significant kidney pathology occurs in untreated diabetes as a result of the buildup of extravasated plasma protein in the extravascular matrix in this organ.

The experiment consisted of giving both normal and 30 diabetic rats daily intraperitoneal doses of the agent aminoguanidine hydrochloride at a dose of 25 mg per kilogram of body weight, for a period of 16 weeks. The hydrochloride salt of aminoguanidine was used as it is more soluble and less irritating than the parent free 35 base compound. Diabetes was induced prior to drug therapy with a single dose of streptozotocin. Control animals, both diabetic and normal, received no drug.

At the end of the agent therapy, animals were sacrificed and the kidneys were removed. Each organ was removed from its capsule and the medulla was removed. The remainder of the tissue, principally containing 5 glomeruli, was frozen on dry ice and stored at -70°C. Tissue from five animals in each treatment group was combined for processing.

To prepare glomerular basement membranes, tissue was cut 10 into slices and passed through a series of sieves (170, 100 and 270) to separate glomeruli from tubules and other undesired tissue elements as described (Beisswenger, P.J., Spiro, R.G., Diabetes, 22:180-193, 1973). Glomerular purity was found to be 80-90%. The final 15 material was collected and centrifuged at 1500 rpm for fifteen minutes to pellet the glomeruli, which were frozen at -70°C.

Thawed isolated glomeruli were then disrupted by 20 treatment in a Branson Sonifier 200 cell disrupter for four one-minute intervals on ice with a one-minute rest between sonications. Samples were examined in a phase contrast microscope to ensure that all of the glomeruli were disrupted. Glomerular basement membranes were then 25 pelleted by centrifugation at 3000 rpm for ten minutes, washed with 1 M sodium chloride followed by distilled water. The remaining pellet of purified glomerular basement membranes was frozen and lyophilized.

30 An enzyme immunoassay was used to measure the amount of serum immunoglobulin G (IgG) that became bound to the glomerular basement membranes of the normal and diabetic animals after treatment with and without the agent. To measure IgG, 6 mg samples of lyophilized glomerular 35 basement membrane tissue was suspended in 0.5 mM of 0.05 M carbonate buffer, pH 7.6, and 0.5 mM of a 1:5,000 dilution of rat anti-IgG antibody conjugated to alkaline

phosphates (Dynatech Corp.) was added. The mixture was incubated overnight in polystyrene tubes which were preblocked by incubation for two hours in 3% goat serum plus 0.05% Tween 20 in phosphate buffered saline (PBS),  
5 followed by two rinses in PBS plus Tween.

After overnight incubation to allow the antibody to bind to any IgG crosslinked to the glomerular basement membranes, the membranes were pelleted by centrifugation  
10 at 3200 rpm for five minutes and were washed free of the unbound antibody-enzyme conjugate with four rinses with PBS plus Tween followed by three rinses with distilled water. To measure the amount of antibody-enzyme conjugate remaining bound, 0.5 mM of substrate solution  
15 (containing 1 mg/mL para-nitrophenylphosphate in 10% diethanolamine, pH 9.8), was added and incubations were carried out for 30 minutes at room temperature. The reaction was stopped with the addition of 0.2 mL of M sodium hydroxide, and the absorbance at 400 nm was  
20 measured.

Figure 4 shows the results of this experiment. As can be seen, diabetic animals had a high level of IgG bound to their glomerular basement membranes ("D") and normal  
25 animals had about one-fifth the amount ("N"). Diabetic animals which received daily doses of aminoguanidine hydrochloride showed the same low level of IgG in normal animals ("D + I"). Normal animals receiving the drug had about the same low level ("N + I").

30 These experiments indicated that aminoguanidine prevented the trapping and accumulation of this plasma protein on the rat glomerular basement membranes. Presumably, the trapping of this and other serum proteins in the kidney,  
35 eye, on artery walls, and in other tissues known to be affected from this pathology would likewise be reduced.

Trapping of lipoproteins on artery walls is known to contribute to atherosclerotic disease.

These in vivo experiments provide further evidence from 5 the in vitro experiments that this type of drug therapy has benefit in reducing the pathology associated with the advanced glycosylation of proteins and the formation of crosslinks between proteins and other macromolecules. Drug therapy may be used to prevent the increased 10 trapping and crosslinking of proteins that occurs in diabetes and aging which leads to sequela such as arterioal disease, including renal disease, hypertension, retinal damage, and extra-vascularly, damage to tendons, ligaments and other joints. This therapy might retard 15 atherosclerosis and connective tissue changes that occur with diabetes and aging. Both topical, oral and parenteral routes of administration to provide therapy locally and systematically are contemplated.

20

#### EXAMPLE V

Aorta samples from the same groups of animals described in Example IV above were subjected to analysis for Advanced Glycosylation Endproducts (A.G.E.) content and 25 solubility.

Aortas were finely minced with dissecting scissors, delipidated with 5 mL of chloroform: methanol (2:1), washed 5 times with buffer, and divided into aliquots for 30 the following assessments of cross-linking:

- (A) Specific fluorescence of collagen after complete solubilization by proteinase k and pepsin.
- 35 (B) Solubility in 0.5M acetic acid was determined after 2 hours of extraction at 25°C and 24 hours at 4°C.

30

- (C) Solubility after cyanogen bromide cleavage at 30°C for 18 hours was determined.
- (D) Solubility after degradation by pepsin (1.0 mg/mL) in 0.1M acetate buffer, pH 4.1, at 37°C for 48 hours.

5

After treatment for the prescribed period, soluble material was separated from insoluble material by centrifugation (50,000 x g, 1 hour), and all fractions 10 were lyophilized and hydrolyzed in 6M HCl for determination of total hydroxyproline. The results of these analyses are set forth in Table I, below.

**TABLE I**Percent collagen solubilized by:

		<u>Advanced glycosylation products*</u>	<u>0.5M acetic acid</u>	<u>CNBr</u>	<u>Pepsin</u>
<b>5</b>	<b>Group</b>	<b>Treatment</b>			
			<u>products*</u>	<u>0.5M acetic acid</u>	<u>CNBr</u>
	Normal	None	3.5 ± 0.11	8.0 ± 0.3	12.2 ± 0.1
	Diabetic	None	19.4 ± 0.8	2.0 ± 0.2	4.4 ± 0.1
<b>10</b>					15.0 ± 0.2
	Normal	Aminoguanidine	2.8 ± 0.1	18.7 ± 0.3	13.6 ± 0.3
	Diabetic	Aminoguanidine	4.5 ± 0.1	12.6 ± 0.3	10.6 ± 0.1
					52.5 ± 0.2
					46.1 ± 0.4

\*Specific fluorescence per mg hydroxyproline

As can be seen from Table I, accumulation of fluorescent advanced nonenzymatic glycosylation products in aortic connective tissue from untreated diabetic rats was 5.5 times greater than that in aortic tissue from untreated 5 normal rats. In contrast, the level in aortic tissue from aminoguanidine-treated diabetic rats was only 1.3 times that of untreated normal rats, despite exposure to identical levels of hyperglycemia for the same period of time. These data indicate that accumulation of advanced 10 nonenzymatic glycosylation products is inhibited by aminoguanidine in vivo.

The percentage of aortic connective tissue solubilized by each of the three specified procedures (acetic acid, 15 CNBr, and pepsin) was significantly reduced in samples from untreated diabetic animals compared to those from normal animals. Diabetic aortic connective tissue from untreated rats was 9 times more cross-linked than normal as assessed by acetic acid solubility, 2.8 times more as 20 assessed by CNBr digestion, and 3.4 times as cross-linked according to pepsin digestibility.

In contrast, aortic connective tissue from aminoguanidine-treated diabetic animals was only 1.1 to 25 1.4 times more cross-linked than normal, despite exposure to identical levels of hyperglycemia for the same period of time. These data indicate that aminoguanidine prevents hyperglycemia-induced increases in nonenzymatic collagen cross-linking in vivo.

EXAMPLE VI

Aorta samples from the same group of animals described in Example IV above, were subjected to analysis for cross-linking of lipoprotein to collagen, using an enzyme immunoassay. A standard ELISA procedure was employed, 35 using antiserum to rat apolipoprotein-B raised in

rabbits, peroxidase-labeled anti-rabbit antibody, and standard chromogenic reagents to detect quantity of antibody bound.

5 The results are set forth in Table II, below.

TABLE II  
TREATMENT GROUP      LIPOPROTEIN BOUND PER MG

COLLAGEN

10	Normal	0.69
	Diabetic	1.86
	Normal + Aminoguanidine	0.53
	Diabetic + Aminoguanidine	0.64

15 These data indicate that lipoprotein accumulation in the macrovasculature, an early event in the atherogenic process, may be treatable by aminoguanidine administration.

20

EXAMPLE VII

In order to assess the possible role of hyperglycemia-induced matrix modifications in this process, demineralized bone matrix particles from 35 week old 25 normal Long-Evans rats were prepared. Matrix is incubated in phosphate buffered saline alone (PBS), PBS containing various sugar precursors of AGE (PBS-G), and PBS with sugars plus the AGE-inhibitor aminoguanidine (PBS-G + AG). After incubation, the matrix is washed and 30 implanted subcutaneously in normal rats. Twelve days after implantation,  $^{45}\text{CaCl}_2$  is injected to determine implant mineralization, and alkaline phosphatase activity is measured to assess osteoblast function. Duplicate specimens are fixed, embedded and stained for histologic 35 evaluation.

The AGE precursor glycolaldehyde increased the matrix AGE content (by specific fluorescence) over twofold, while inhibiting bone differentiation more than 90% ( $^{45}\text{CaCl}_2$  uptake, alk phos, and histology). In contrast,  
5 simultaneous incubation with the AGE-inhibitor aminoguanidine reduced fluorescence to normal, and restored bone differentiation to 80% of control.

EXAMPLE VIII

- 10 New Zealand white rabbits, with induced, long-term diabetes ( $12.7 \pm 3.2$  months) are used to study the effects of a test compound on red blood cell (RBC) deformability. If glucose-mediated crosslinking of red  
15 blood cell components results in less deformable, more rigid membrane, then therapy should prevent this change in new red cells. Red blood cells already in existence at the initiation of therapy would be unaffected; because RBCs are replaced frequently newly formed red blood cells  
20 would be exposed to the therapy. The diabetic rabbits ( $n=6$ ) had a mean blood sugar of  $292.6 \pm 84.6$  mg/dl before and after a two-month dosage regimen. The test compound is administered at a rate of 100 mg/kg/day by oral gavage.
- 25 The deformability index (DI) (filtration rate of buffer/filtrate rate of suspended RBCs; hematocrit = 4.0%) is used as a measure of RBC deformability. Buffer and suspended RBCs are filtered through a  $3 \mu$  micropore  
30 membrane (Nucleopore Corp., Pleasanton, CA) with a pressure of -20 cm H<sub>2</sub> at 37°C. A reference range for RBC deformability (2.67 to 4.84, mean  $4.02 \pm 0.69$ ) and % hemoglobin glycosylation (1.7 to 3.96, mean  $2.60 \pm 0.70$ ) is obtained from a group of normal New Zealand white  
35 rabbits ( $n=14$ ), matched for age, sex and weight.

The results are given in Table III, below for diabetic New Zealand white rabbits dosed with 100 mg/kg/day aminoguanidine.

5

TABLE III

Red Blood Cell Deformability of Long-Term  
Diabetic Rabbits on Aminoquanidine HCl

	<u>Duration of Dosing (weeks)</u>	<u>Red Blood Cell Deformability Index</u>
10	0	18.32 ± 6.03
	4	7.17 ± 3.12
	8	6.83 ± 2.97
	12	4.64 ± 1.58
	16	4.44 ± 1.33
	20	4.14 ± 1.06
20	Diabetes causes an increase in the deformability index from 4.0 to 18. The results show that aminoguanidine administration reduces the diabetes-induced decreased deformability (increased deformability index) value to normal after 12 weeks. In a separate experiment,	
25	aminoguanidine hydrochloride was administered daily to rabbits at the time of induction of diabetes. The RBC deformability index in these animals never became abnormal. These experiments indicate that aminoguanidine prevents diabetes-induced RBC deformability changes; the	
30	rabbits with delayed treatment showed positive effect over time presumably as old red cells, which already had been cross-linked and were less deformable, were replaced with new red cells under the influence of aminoguanidine to inhibit cross-linking.	

35

EXAMPLE IX

Streptozotocin-diabetic male Lewis rats were treated for a 9-month time period with daily doses of aminoguanidine hydrochloride of 0, 6.25, 12.5, 25, and 50 mg/kg/day.

After the treatment period, collagen in tail tendon fiber was subjected to solubility determination. Ten mg samples were incubated with gentle rocking for 5 hours at 4°C in 5 ml of 0.5M acetic acid containing 1 mg pepsin.

- 5 The samples were then centrifuged at 50,000 x g for 1 hour, and the soluble and insoluble fraction separated by decanting. Each fraction was hydrolyzed in 6N HCl and total hydroxyproline measured. The results are set forth in Table IV, below.

10

TABLE IV

<u>Condition</u>	<u>Aminoguanidine HCl mg/kg/day</u>	<u>Collagen Solubility</u>
15 Normal	0	80.7 ± 3.4%
Diabetic	0	64.8 ± 0.8%
Diabetic	12.5	66.7 ± 1.2%
Diabetic	50	75.9 ± 0.4%
Normal	50	88.2 ± 0.2%

20

- Diabetes of 9 months duration reduced tail tendon collagen solubility from 91% to 8%. Administration of AG HCl at doses from 6.25 up to 50 mg/kg/day orally significantly prevented this change in a dose-dependent manner, with the highest dose preventing 80% of the diabetes induced cross-linking.

EXAMPLE X

- 30 The effect of aminoguanidine administration on collagen cross-linking was examined in a genetically-diabetic animal model, the BB/Worcester rat. Once the animals become diabetic, daily insulin injections are essential for survival. Glucose levels are maintained at a 35 moderate level (250-350 mg %), much lower than in the streptozotocin-diabetic animals (>500 mg%).

Diabetic and non-diabetic controls were treated orally with aminoguanidine hydrochloride at 12.5 and 50

mg/kg/day for 6 months. Control animals were dosed with water only. Tail tendon collagen solubility was then determined by the pepsin method described in Example IX. The results are set forth in Table V, below.

5

TABLE V

<u>Condition</u>	<u>Aminoguanidine HCl mg/kg/day</u>	<u>Collagen Solubility</u>
10 Normal	0	80.7 + 3.4%
Diabetic	0	64.8 + 0.8%
Diabetic	12.5	66.7 + 1.2%
Diabetic	50	75.9 + 0.4%
Normal	50	88.2 + 0.2%

15

These data show that the solubility of tail tendon collagen was reduced from 81% to 65% with diabetes of 6 months' duration but prevented significantly, in a dose-dependent manner, by both aminoguanidine treatments.

20

Diabetic BB/Worcester rat collagen showed less decrease in solubility over the 6 month period than streptozotocin-diabetic rats presumably because of the lower degree of hyperglycemia and lower concentration of glucose to which collagen was exposed chronically.

25

EXAMPLE XI

The following method was used to evaluate the ability of the compounds of the present invention to inhibit glucose-mediated development of fluorescence of bovine serum albumin (BSA), a measure of cross-linking. Compounds were incubated under aseptic conditions at a concentration of 1 mM with 400 mM glucose and 100 mg/mL BSA in a 1.5 M sodium phosphate buffer, pH 7.4.

35

Samples of the incubation mixture were taken immediately and after 1 week incubation at 37°C for measurement of fluorescence. For each test compound, control incubations in buffer were made of compound alone (C),

compound plus glucose (G+C), and compound plus BSA (B+C). An additional set of incubations of glucose and BSA (B+G) were prepared as the baseline controls against which were measured the ability of the compounds to inhibit. Each 5 incubation was made in triplicate.

Fluorescence (excitation, 370 nm; emission, 440 nm) was measured on each sample after a 100-fold dilution in distilled water.

10 The % inhibition of browning of each test compound was calculated as follows. Each OF represents the fluorescence measurement of that sample after 1 week incubation less its fluorescence before incubation.

15 % inhibition =  

$$\frac{F_{B+G} - [ F_{B+G+C} - ( F_G + F_{G+C} + F_{B+C} ) ]}{F_{B+G}} \times 100$$

20 where B=BSA, G=glucose, and C-test compound.

Percent inhibition of browning by various test compounds at 1 mM:

25 43.0% L-lysine monohydrochloride;  
 20.8% 3-mercaptop-D-valine;  
 16.7% L-ornithine monohydrochloride;  
 31.5% DL-2,4-diaminobutyric acid dihydrochloride;  
 11.0% L-cysteine monohydrochloride; and  
 30 30.2% 4-aminobutyric acid.

#### EXAMPLE XII

	<u>Tablet</u>	<u>mg/tablet</u>
35	Compound of Formula I	50
	Starch	50
	Mannitol	75

Magnesium stearate	2
Stearic acid	5

The compound, a portion of the starch and the lactose are  
 5 combined and wet granulated with starch paste. The wet  
 granulation is placed on trays and allowed to dry  
 overnight at a temperature of 45°C. The dried  
 granulation is comminuted in a comminutor to a particle  
 size of approximately 20 mesh. Magnesium stearate,  
 10 stearic acid and the balance of the starch are added and  
 the entire mix blended prior to compression on a suitable  
 tablet press. The tablets are compressed at a weight of  
 232 mg. using a 11/32" punch with a hardness of 4 kg.  
 These tablets will disintegrate within a half hour  
 15 according to the method described in USP XVI.

EXAMPLE XIII

	<u>Lotion</u>	<u>mg/g</u>
20	Compound of Formula I	1.0
	Ethyl alcohol	400.0
	Polyethylene glycol 400	300.0
	Hydroxypropyl cellulose	5.0
	Propylene glycol	to make 1.0 g

25

EXAMPLE XIV

	<u>Oral Rinse</u>	
	Compound of Formula I:	1.4 %
30	Chlorhexidine gluconate	0.12 %
	Ethanol	11.6 %
	Sodium saccharin	0.15 %
	FD&C Blue No. 1	0.001%
	Peppermint oil	0.5 %
35	Glycerine	10.0 %
	Tween 60	0.3 %
	Water to	100 %

EXAMPLE XVToothpaste

Compound of Formula I:	5.5 %
5 Sorbitol, 70% in water	25 %
Sodium saccharin	0.15 %
Sodium lauryl sulfate	1.75 %
Carbopol 934, 6% dispersion in water	15 %
Oil of Spearmint	1.0 %
10 Sodium hydroxide, 50% in water	0.76 %
Dibasic calcium phosphate dihydrate	45 %
Water to	100 %

EXAMPLE XVI

15

To further study the ability of inhibitors of nonenzymatic browning to prevent the discoloration of protein on a surface, such as that which occurs on the tooth surface, the following surface browning experiment 20 is performed. As a substitute for a pellicle-covered tooth surface, unexposed and developed photographic paper is used to provide a fixed protein (gelatin, i.e., collagen) surface on a paper backing. Five millimeter circles are punched and immersed for one week at 50°C in 25 a solution of 100 mM glucose-6-phosphate in a 0.5 M phosphate buffer, pH 7.4, containing 3 mM sodium azide. Glucose-6-phosphate is a sugar capable of participating in nonenzymatic browning at a more rapid rate than glucose. In addition to the glucose-6-phosphate,

30 chlorhexidine and/or a compound of Formula I are included. After incubation, the gelatin/paper disks are rinsed with water, observed for brown color, and photographed.

35 Incubation of the disks in glucose-6-phosphate alone shows slight brown color versus disks soaked in buffer alone. Inclusion of chlorhexidine (in the form of

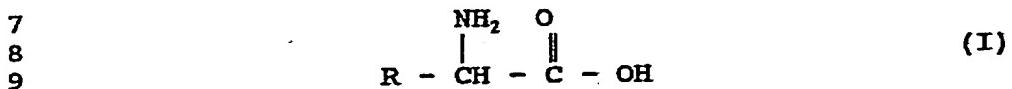
Peridex® at a final concentration of 0.04% chlorhexidine) shows significant browning. Addition of a compound of Formula I to the chlorhexidine inhibits browning of the gelatin, as does inclusion of a compound of Formula I in 5 the absence of chlorhexidine.

The slight brown color formed by the action of glucose-6-phosphate on the gelatin surface alone and its prevention by a compound of Formula I demonstrates the utility of 10 the present invention in preventing nonenzymatic browning of tooth surfaces. The enhanced browning in the presence of chlorhexidine and its prevention with a compound of Formula I demonstrates the utility of the present invention in preventing the anti-plaque agent-enhanced 15 nonenzymatic browning which occurs with chlorhexidine.

This invention may be embodied in other forms or carried out in other ways without departing from the spirit or essential characteristics thereof. The present 20 disclosure is therefore to be considered as in all respects illustrative and not restrictive, the scope of the invention being indicated by the appended Claims, and all changes which come within the meaning and range of equivalency are intended to be embraced therein.

**WHAT IS CLAIMED IS:**

1 1. A method for treating an animal to inhibit the  
2 formation of advanced glycosylation end products of a  
3 target protein within said animal, said method comprising  
4 administering to said animal an effective amount of a  
5 pharmaceutical composition, said pharmaceutical  
6 composition comprising an agent of the formula



10 wherein R is selected from the group consisting of  
11 hydrogen; lower alkyl, optionally substituted by one or  
12 two hydroxyl, thiol, phenyl, hydroxyphenyl, lower  
13 alkylthio, carboxy, aminocarboxy or amino groups; and  
14 their biocompatible and pharmaceutically acceptable acid  
15 addition salts; capable of reacting with the carbonyl  
16 moiety of the early glycosylation product formed by the  
17 initial glycosylation of said target protein, together  
18 with a carrier therefor.

1 2. The method of Claim 1, wherein said target protein  
2 is a structural protein.

1   3. The method of Claim 1, wherein said target protein  
2   is selected from the group consisting of collagen,  
3   elastin lens protein, blood vessel walls, nerve protein  
4   and glomerular basement membrane.

1   4. The method of Claim 1, wherein said pharmaceutical  
2 composition comprises said agent and a pharmaceutically  
3 acceptable carrier.

- 1 5. The method of Claim 1, wherein said agent is L-
- 2 lysine monohydrochloride or another pharmaceutically
- 3 acceptable salt.
  
- 1 6. The method of Claim 1, wherein said agent is DL-2,4-
- 2 diaminobutyric acid.
  
- 1 7. The method of Claim 1, wherein said agent is
- 2 cysteine monohydrochloride or another pharmaceutically
- 3 acceptable salt thereof.
  
- 1 8. The method of Claim 1, wherein said agent is 3-
- 2 mercapto-D-valine.
  
- 1 9. The method of Claim 1, wherein said agent is 4-
- 2 aminobutyric acid.
  
- 1 10. The method of Claim 1, wherein said agent is L-
- 2 ornithine monohydrochloride or another pharmaceutically
- 3 acceptable salt thereof.
  
- 1 11. The method of Claim 1, wherein said pharmaceutical
- 2 composition is administered parenterally.
  
- 1 12. The method of Claim 1, wherein said pharmaceutical
- 2 composition is administered topically.
  
- 1 13. The method of Claim 1, wherein said pharmaceutical
- 2 composition is prepared in an ointment form and said
- 3 agent is present in an amount of up to about 10% by
- 4 weight.
  
- 1 14. The method of Claim 1, wherein said pharmaceutical
- 2 composition is administered orally.

1 15. The method of Claim 1, wherein said pharmaceutical  
2 composition is administered in an amount of up to about  
3 25 mg/kg body weight of said animal.

1 16. The method of Claim 1, adapted for the treatment of  
2 the complications of diabetes and aging caused by the  
3 accumulation advanced glycosylation endproducts in the  
4 body.

1 17. The method of Claim 1, adapted for the treatment of  
2 diabetic kidney disease.

1 18. The method of Claim 1, adapted for the treatment of  
2 glomerulosclerosis.

1 19. The method of Claim 1, adapted for the treatment of  
2 peripheral vascular disease.

1 20. The method of Claim 1, adapted for the treatment of  
2 atherosclerosis.

1 21. The method of Claim 1, adapted for the treatment of  
2 arteriosclerosis obliterans.

1 22. The method of Claim 1, adapted for the treatment of  
2 peripheral neuropathy.

1 23. The method of Claim 1, adapted for the treatment of  
2 retinopathy.

1 24. The method of Claim 1, adapted for the treatment of  
2 cataracts.

1 25. The method of Claim 1, adapted for the treatment of  
2 stroke.

1 26. The method of Claim 1, adapted for the treatment of  
2 hypertension.

1 27. The method of Claim 1, adapted for the treatment of  
2 periarticular rigidity.

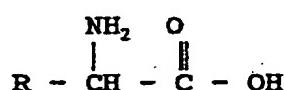
1 28. The method of Claim 1, adapted for the treatment of  
2 osteoarthritis.

1 29. The method of Claim 1, adapted for the treatment of  
2 loss of elasticity and wrinkling of skin.

1 30. The method of Claim 1, adapted for the treatment of  
2 stiffening of joints.

1 31. The method of Claim 1, adapted for the treatment of  
2 glomerulonephritis.

1 32. A composition for inhibiting the advanced  
2 glycosylation of a target protein comprising an agent  
3 capable of reacting with the carbonyl moiety of the early  
4 glycosylation product formed by the initial glycosylation  
5 of the target protein of the formula



(I)

12 wherein R is selected from the group consisting of  
13 hydrogen; lower alkyl, optionally substituted by one or  
14 two hydroxyl, thiol, phenyl, hydroxyphenyl, lower  
15 alkylthio, carboxy, aminocarboxy or amino groups; and  
16 their biocompatible and pharmaceutically acceptable acid  
17 addition salts; capable of reacting with the carbonyl  
18 moiety of the early glycosylation product formed by the  
19 initial glycosylation of said target protein, together  
20 with a carrier therefor.

1 33. The composition of Claim 32, wherein said  
2 composition and said agent are useful for the treatment  
3 of the complications of diabetes and aging caused by the  
4 accumulation of advanced glycosylation endproducts in  
5 mammals.

1 34. The composition of Claim 32, wherein said agent is  
2 L-lysine monohydrochloride or another pharmaceutically  
3 acceptable salt thereof.

1 35. The composition of Claim 32, wherein said agent is  
2 DL-2,4-diaminobutyric acid.

1 36. A composition of Claim 32, wherein said compound is  
2 cysteine monohydrochloride or another pharmaceutically  
3 acceptable salt thereof.

1 37. The composition of Claim 32, wherein said agent is  
2 3-mercaptop-D-valine.

1 38. The composition of Claim 32, wherein said agent is  
2 4-aminobutyric acid.

1 39. The composition of Claim 32, wherein said agent is  
2 L-ornithine monohydrochloride or another pharmaceutically  
3 acceptable salt thereof.

1 40. A pharmaceutical composition for administration to  
2 an animal to inhibit the advanced glycosylation of a  
3 target protein within said animal, comprising a  
4 pharmaceutically effective amount of an agent capable of  
5 reacting with the carbonyl moiety of the early  
6 glycosylation product formed by the initial glycosylation  
7 of said target protein, and a pharmaceutically acceptable  
8 carrier of the formula

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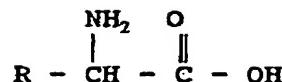
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(I)

15 wherein R is selected from the group consisting of  
 16 hydrogen; lower alkyl, optionally substituted by one or  
 17 two hydroxyl, thiol, phenyl, hydroxyphenyl, lower  
 18 alkylthio, carboxy, aminocarboxy or amino groups; and  
 19 their biocompatible and pharmaceutically acceptable acid  
 20 addition salts; capable of reacting with the carbonyl  
 21 moiety of the early glycosylation product formed by the  
 22 initial glycosylation of said target protein, together  
 23 with a carrier therefor.

1 41. The composition of Claim 40 wherein said composition  
 2 and said agent are useful for the treatment of the  
 3 complications of diabetes and aging caused by the  
 4 accumulation of advanced glycosylation endproducts in  
 5 mammals.

1 42. The pharmaceutical composition of Claim 40, wherein  
 2 said agent is L-lysine monohydrochloride or another  
 3 pharmaceutically acceptable salt thereof.

1 43. The pharmaceutical composition of Claim 40, wherein  
 2 said agent is 2,3-diamino succinic acid.

1 44. The pharmaceutical composition of Claim 40, wherein  
 2 said agent is L-cysteine monohydrochloride or another  
 3 pharmaceutically acceptable salt thereof.

1 45. The pharmaceutical composition of Claim 40, wherein  
 2 said agent is mercapto-D-valine.

1 46. The pharmaceutical composition of Claim 40, wherein  
 2 said agent is 4-aminobutyric acid.

1 47. The pharmaceutical composition of Claim 40, wherein  
2 said agent is L-ornithine monohydrochloride or another  
3 pharmaceutically acceptable salt thereof.